

Microwave Component Time Delays for the 70-Meter Antennas

R. Hartop

Radio Frequency and Microwave Subsystems Section

The X-band feed assemblies in the 64-meter antennas have been redesigned to accommodate the upgrading to 70 meters and the associated surface reshaping. To maintain time delay data logs, new calculations have been made of the microwave component delays for the XRO Mod IV X-band (8.4 to 8.45 GHz) feed assembly that has been installed at DSS-63, and will soon be implemented at DSS-43 and DSS-14.

I. Introduction

Since the microwave time delays were last calculated for the DSN 64-meter antennas [1], the feed configurations at S- and X-band have remained the same, despite some other changes to the antennas (such as the addition of L-band). But the extension of the antennas from 64 meters to 70 meters and the reshaping of the surfaces to further increase the gain has required that the XRO Mod III X-band feed be replaced.

The Mod III feed [2] was designed to provide more efficient illumination of the 64-meter antennas in time for the Voyager 1 encounter with Jupiter. With the current reshaping of the antenna main reflector and subreflector, the dual hybrid mode feed pattern produced by the Mod III feed is no longer advantageous. Thus, the Mod IV feed assembly returns to the DSN standard 22.4 dB gain gaussian beam design. The feed assembly incorporates a Bethe hole coupler for precision phase calibration and a new feedhorn extension that obviates the need to relocate the traveling wave masers within the feed-cone. The coupler and feedhorn extension will be reported on later.

II. MOD IV XRO Feed Assembly

The new feed assembly is shown in Fig. 1. A schematic of its layout is shown in Fig. 2. Like the Mod III feed, the new feed incorporates an orthogonal mode transducer to provide simultaneous right- and left-hand circular polarization. Thus, there are two paths to consider for time delays. The quarter-wave plate polarizer is rotatable by 90 degrees to reverse the polarization senses at each output port in the event that the primary traveling wave maser (normally RCP) should fail.

The microwave component time delays, τ_g , (see Table 1) were computed at 8420 MHz using the methods described in [1], with the exception of the new feedhorn. In this case, a new computer program developed at JPL was used. The program calculates the modes propagating (and reflecting) from each discontinuity to find the total delay from the feedhorn throat to the radiating aperture of the extension. This value was then adjusted for the distance to the phase center, which lies in front of the aperture for this feed assembly. As before, the centerline of the TWM coupler (at the Type N coaxial connector) is chosen as the interface to the calibration signal equipment.

Acknowledgment

D. Hoppe performed the computer analysis to determine the feedhorn time delay.

References

- [1] R. Hartop, "Microwave Time Delays in the DSN 34- and 64-Meter Antennas," *DSN Progress Report 42-51*, vol. March-April, pp. 183-185, Jet Propulsion Laboratory, Pasadena, Calif., June 15, 1979.
- [2] R. Hartop, "New X-Band Antenna Feeds for the DSN 64-Meter Stations," *DSN Progress Report 42-52*, vol. May-June, pp. 71-74, Jet Propulsion Laboratory, Pasadena, Calif., August 15, 1979.

Table. 1. Microwave component time delays for XRO Mod IV feed assembly at 8420 MHz

Item	τ_g , ns	
Feedhorn	3.479	
Phase calibration coupler	0.477	
Rotary joints, 2, total	0.424	
Polarizer	0.444	
	Straight Path to TWM No. 2	Side Path to TWM No. 1
Orthogonal mode junction	0.707	0.709
Waveguide twist	—	0.511
Waveguide switch	0.342	0.342
Waveguide	—	0.153
TWM coupler (to center)	0.153	0.153
TOTAL delay	6.026	6.690

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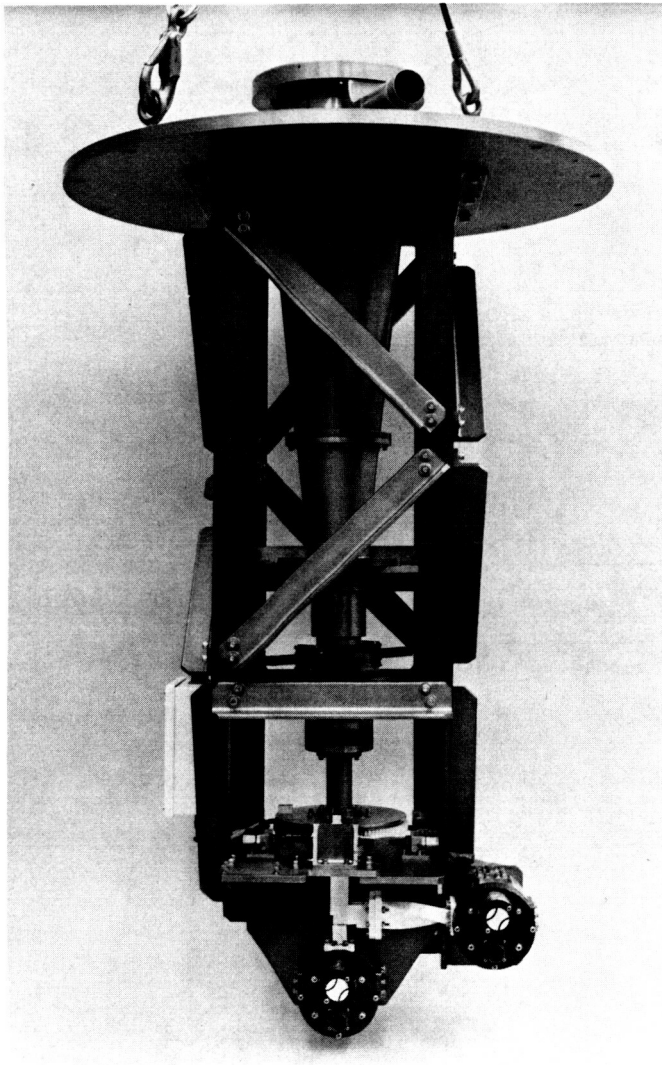


Fig. 1. XRO Mod IV feed assembly

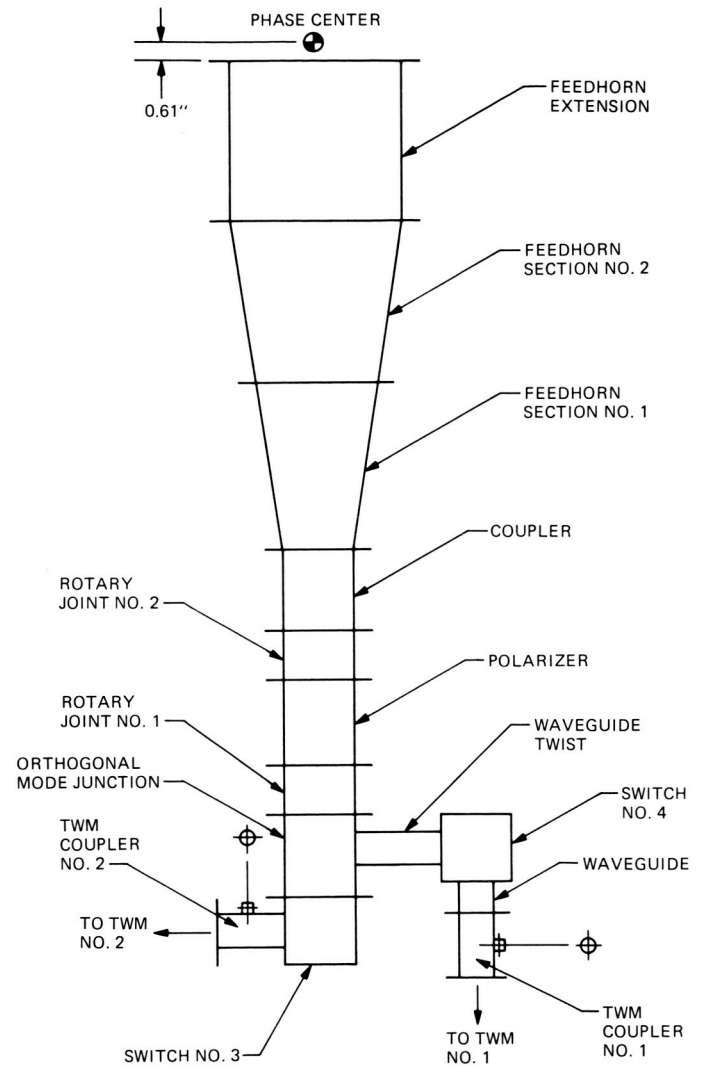


Fig. 2. XRO Mod IV feed layout

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Z-Corrections for DSN 70-Meter Antenna Ranging Calibration

A. G. Cha

Radio Frequency and Microwave Subsystems Section

This article documents the Z-corrections of the DSN 70-m dual-shaped reflector antennas. These corrections to the group delay time measured by the translator are required before the 70-m antennas can be used for ranging.

I. Introduction

This article summarizes the Z-corrections needed for 70-m DSS ranging calibration. According to [1],¹ the Z-corrections consist of four terms: τ_c , τ_d , τ_3 , and τ_4 , as shown in Fig. 1 and Eq. (1). These numbers come from three separate sources. The τ_4 X-band corrections are discussed in a separate article in this issue [2]. The τ_3 and τ_4 S-band corrections are discussed in [1] and [3]. Details on the derivations of τ_c and τ_d are presented in Section III.

$$Z_{\text{Correction}} = Z_{\text{Translator}} - (\tau_3 + \tau_4 + (\tau_c - \tau_d)_{\text{Up}} + (\tau_c - \tau_d)_{\text{Down}}) \quad (1)$$

II. Derived Group Delay Time

Tables 1 (X-band) and 2 (S-band) summarize the derived group delay time for the 64-m and 70-m antenna configurations.

III. One-Way Ranging Equation for τ_c and τ_d Corrections

With reference to Fig. 2, a theoretical one-way ranging equation can be written that does not involve a detailed ranging system configuration and hardware. The terminology used in this article follows that of [1] and [4]; range is distance and delay is the group delay time.

A. Phase Delay

Figure 2 shows a Cassegrainian antenna in a microwave system. Point A is the reference location for ranging. Point B is the target location. The distance R is the topocentric range of the target [1]. The phase of a continuous carrier wave received at Point B is $\exp[j(\omega t + \Phi)]$. Following [5] and [6],

$$\Phi = \Phi_{\text{wg}} + \Phi_{\text{ant}}(\omega) + kL - kR \quad (2)$$

where $\omega = 2\pi f$, and f is the frequency. The meanings of each term on the right side of Eq. (2) are as follows. The first term is the phase delay from the RF transmitter (uplink) or receiver (downlink) to the feedhorn phase center. The second term is the phase delay in the Cassegrainian antenna from the feedhorn phase center to the aperture plane. The third term is the

¹Also refer to *DSN/Flight Project Interface Design Handbook*, TDA 810-5, Vol. 2 TRK-30 (internal document), Jet Propulsion Laboratory, Pasadena, Calif., to be published 1987.

phase correction term needed when the aperture plane does not contain the reference location. These are the three correctional terms to the fourth term, which corresponds to the topocentric range R , the distance from the reference point of the ground antenna to the referenced point of the spacecraft antenna.

B. Group Delay Time

The Group delay of the RF signal from the RF transmitter to the target location B is (from [5])

$$\begin{aligned} t &= -\frac{d\Phi}{d\omega} \\ &= -\frac{d\Phi_{wg}}{d\omega} - \frac{d\Phi_{ant}}{d\omega} + \frac{R-L}{V_c} \end{aligned} \quad (3)$$

where V_c is the free space light velocity and is 2.9979×10^{10} cm/s. The first term in Eq. (3) is the group delay time from the RF transmitter (or receiver) to the feedhorn phase center. The second term is the group delay time in the Cassegrainian antenna.

C. Air Path in Cassegrainian Antennas

A ranging path length may be artificially defined as the product of group delay time in Eq. (3) and free space light velocity.

$$\text{Path length} = -V_c \frac{d\Phi_{wg}}{d\omega} - V_c \frac{d\Phi_{ant}}{d\omega} + R - L \quad (4)$$

The second term in Eq. (4) is commonly referred to as the air path in the Cassegrainian antenna. For convenience "equivalent path length" is similarly defined in this article for any waveguide component in the ranging system as the product of group delay time and free space light velocity. This will be applied to the dichroic delay at the X-band later. Next, the air path for 64-m and 70-m antennas is derived using geometric optics and aperture theory. The theoretical analysis was made in [5] and [6]. Only the results are applied in this article.

IV. 64-Meter Antenna Air Path and Delay

For classical Cassegrainian antennas consisting of a parabolic main reflector and a hyperbolic subreflector, the air path from the feedhorn phase center to the aperture is given by

$$-V_c \frac{d\Phi_{ant}}{d\omega} = \text{Air path} = f + 2a + d \quad (5)$$

where

f = Focal length of the paraboloid

$2a$ = Distance between vertices of the two branches of the hyperbola used in defining the Cassegrainian subreflector

d = Distance from main reflector vertex to aperture plane (Fig. 2)

It is shown in [5] and [6] that Eq. (5) is exact in the context of geometric optics (GO) and aperture theory. Equation (5) holds equally in the tricone feed geometry, where the feed and subreflector are tilted relative to the main reflector axis.

When applied to 64-m and 70-m antennas, Eq. (5) must be supplemented by the additional air path of the horn/ellipsoid/dichroic at S-band and delay through the dichroic plate at X-band. These are worked out in [7]. This information is included in Table 3 for reference.

Figure 3 shows the relevant dimensions of the 64-m antenna for ranging. Traditionally, the 64-m antenna aperture plane is taken as the plane defined by the rim of the parabolic main reflector. In this case the distances d and L are given by

$$d = \frac{\rho_{main}^2}{4f} \quad (6)$$

$$L = d + 807.72 \text{ cm} \quad (7)$$

In Eq. (6), ρ_{main} is the radius of the main reflector. Note that d and L are dependent on ρ_{main} . The radius of the 64-m antenna is taken to be 3200.4 cm to be consistent with [7].

V. The 70-Meter Antenna Air Path and Delay

The 70-m antenna geometry relevant to ranging is shown in Fig. 3. The information is extracted from Figs. 3-1, 3-3, and 3-4 of another document.² The air path of the shaped 70-m antenna is not given by such simple algebraic expression as Eq. (5). However, from geometric optics synthesis of the antenna, the air path from feedhorn to plane 2 (Fig. 3) is

$$\text{Air path} = 4835.96 \text{ cm (1903.92 in.)}$$

²A. G. Cha and W. A. Imbriale, "Computer Programs for the Synthesis and Interpolation of 70-Meter Antenna Reflector Surfaces," JPL D-1843 (internal document), Jet Propulsion Laboratory, Pasadena, Calif., Nov. 1984.

The plane 2 is a reference used in the geometric optics synthesis program of the 70-m antenna and is seen from Fig. 3 to be 1893.2 cm above the intersection point *A* of elevation and azimuth axes. Note, as shown in Fig. 3, plane 2 is not defined by the rim of the 70-m antenna main reflector.

The 64-m antenna and aperture plane are shown in Fig. 3. In the following, the 64-m aperture plane, plane 1 in Fig. 3, is also used as the 70-m aperture plane. This simplifies comparisons of the air path and delay of the 64-m and 70-m antennas, as the group delay from the aperture plane to the ground reference point for the two antennas would then be the same. This is shown in Table 3. If other ground reference

points and/or aperture planes are preferred, the antenna air path and group delay from the aperture plane to the ground reference point would then be different for 64-m and 70-m antennas. The new 70-m numbers can be worked out in a straightforward manner from Eqs. (3) and (4).

At press time, it appears that the main reflector surface of DSS 63 is 1.2 cm (0.5 in.) higher than originally designed. Since this variation is not exactly known at present and will be different for each of the three 70-m antennas, future revisions will be issued for each of the antennas when the exact information is available.

Acknowledgment

The author expresses his gratitude for many helpful discussions with R. Hartop, T. Otoshi, and R. Roth during the course of this investigation.

References

- [1] T. Komarek and T. Otoshi, "Terminology of Ranging Measurements and DSS Calibrations," *DSN Progress Report 42-36*, pp. 35-40, Jet Propulsion Laboratory, Pasadena, Calif., Dec. 1976.
- [2] R. Hartop, "Microwave Component Time Delays for the 70-Meter Antennas," *TDA Progress Report 42-89*, Vol. January-March, Jet Propulsion Laboratory, Pasadena, Calif., May 15, 1987.
- [3] T. Otoshi, K. B. Wallace, and R. B. Lyon, "Dual Coupler Configuration at DSS 14 for the Voyager Era," *DSN Progress Report 42-42*, pp. 184-192, Jet Propulsion Laboratory, Pasadena, Calif., Sept. 1977.
- [4] T. Otoshi and K. R. Weld, "Updated Z-Corrections for 64-m DSS Ground Station Delay Calibrations," *DSN Progress Report 42-47*, Vol. July and August, pp. 77-84, Jet Propulsion Laboratory, Pasadena, Calif., 1978.
- [5] A. G. Cha, W. V. T. Rusch, and T. Otoshi, "Microwave Delay Characteristics of Cassegrainian Antennas," *IEEE Trans. on Antennas and Propagation*, Vol. AP-26, No. 6, pp. 860-865, Nov. 1978.
- [6] A. G. Cha, "Phase and Frequency Stability of Cassegrainian Antennas," *Radio Science*, pp. 156-166, Jan. and Feb. 1987.
- [7] R. Hartop, "Microwave Time Delays in the DSN 34- and 64-Meter Antennas," *DSN Progress Report 42-51*, vol. Mar. and Apr. 1979, pp. 183-185, Jet Propulsion Laboratory, Pasadena, Calif., May 15, 1979.

Table 1. X-band delay, ns

Correction	64-m	70-m	Delta
τ_c	152.28	156.79	4.51
τ_d	58.45	58.45	—
τ_3	No X-band uplink at present. Use S-band number for S- uplink and X-downlink.		
τ_4	Straight path 5.986 Side path 6.417	Straight path 6.026 Side path 6.690	0.040 0.273

Table 2. S-band delay, ns

Correction	64-m	70-m	Delta
τ_c	161.16	165.68	4.52
τ_d	58.45	58.45	—
τ_3	22.18	22.18	—
τ_4	19.66	19.66	—

Table 3. Air path and group delay for 64-m and 70-m antennas

Parameter	64-m		70-m	
	S-band	X-band	S-band	X-band
f , cm (in.)	2711 (1067.294)	2711 (1067.294)	—	—
$2a$, cm (in.)	904 (356.057)	904 (356.057)	—	—
d , cm (in.)	945 (371.875)	945 (371.875)	—	—
Air path, horn to aperture plane,* in absence of reflex/dichroic feed, cm (in.)	4560 (1795.226)	4560 (1795.226)	4695 (1848.42)	4695 (1848.42)
Air path due to reflex/dichroic feed, cm (in.)	272 (106.963)	5.49 [†] (2.16)	272 (106.963)	5.49 [†] (2.16)
Air path total, cm (in.)	4832 (1902.189)	4565 (1797.39)	4967 (1955.51)	4700 (1850.58)
One-way group delay, horn to aperture plane, ns	161.16	152.28	165.68	156.79
One-way group delay, aperture plane to reference point, ns	58.45	58.45	58.45	58.45
Net downlink airpath delay, ns	102.71 [‡]	93.83 [‡]	107.23	98.34

*Aperture plane is plane 1, Fig. 3, for both antennas (64-m antenna aperture plane).

[†]Converted from group delay of 0.183 ns [6].

[‡]Agree closely with values for Z_6 in [3].

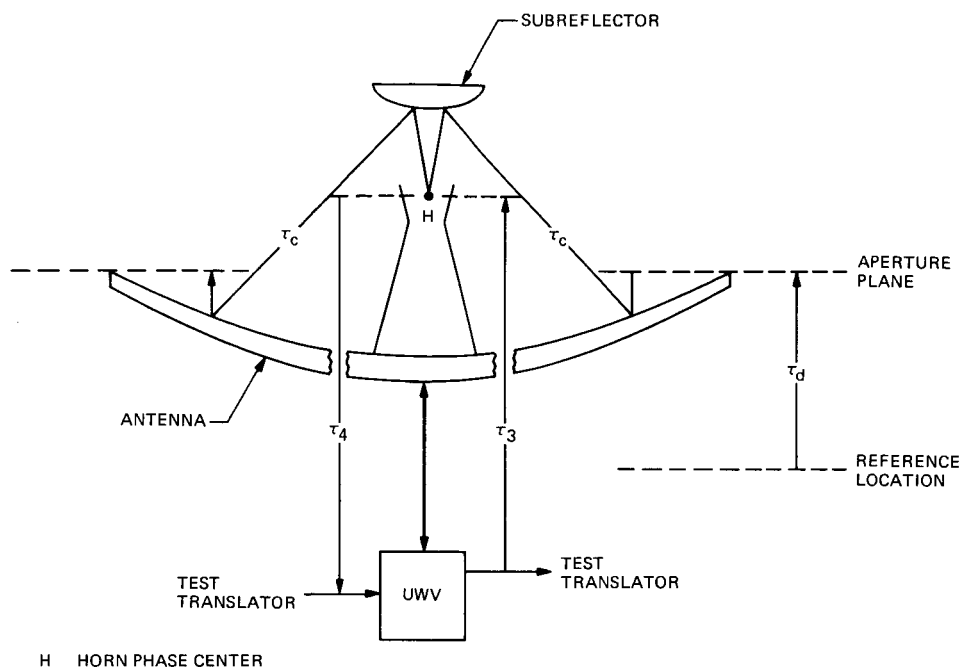


Fig. 1. Definitions of Z corrections

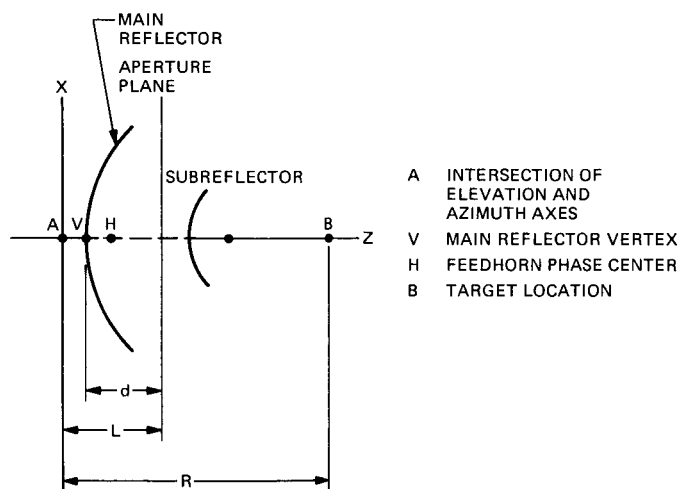


Fig. 2. Cassegrainian antenna in a microwave ranging system

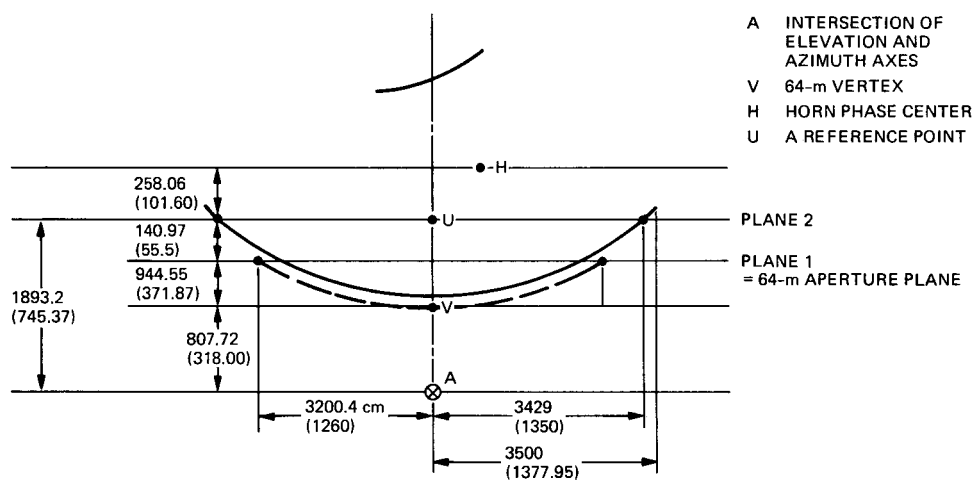


Fig. 3. Geometry of 64-m and 70-m antennas